

Considerations of Technology Transfer Barriers in the Modification of Strategic Superalloys for Aircraft Turbine Engines

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CONSIDERATIONS OF TECHNOLOGY TRANSFER BARRIERS
IN THE MODIFICATION OF STRATEGIC SUPERALLOYS
FOR AIRCRAFT TURBINE ENGINES

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SUMMARY

E-1672 A typical innovation-to-commercialization process for the development of a new hot section gas turbine material requires one to two decades with attendant costs in the tens of millions of dollars. This transfer process is examined to determine the potential rate-controlling steps for introduction of future low strategic metal content alloys or processes. Case studies are used to highlight the barriers to commercialization as well as to identify the means by which these barriers can be surmounted. The opportunities for continuing joint government-university-industry partnerships in planning and conducting strategic materials R&D programs are also discussed.

INTRODUCTION

The development of new jet (gas turbine) engines for aircraft is an extremely costly and competitive business. Billions of dollars were spent and risked (ref. 1) by Pratt & Whitney Aircraft and the General Electric Company, for example, in the development of engines for wide-body aircraft. This "high-risk" industry is, however, critical to the current economic strength of the United States, since aerospace products are major export items, usually second only to agricultural products in making positive contributions to U. S. balance of trade. The nation's defense is also strongly dependent on the existence of high performance gas turbine engines for tactical as well as strategic aircraft.

The United States still holds a commanding lead in world gas turbine technology, but this lead is dependent on a continued flow of advanced technologies - materials, aerodynamics, cooling, instrumentation, etc. For example, in order to meet the multitude of material requirements demanded by the hot, corrosive, and high stress turbine applications, many metallic elements must be combined in the correct proportions to achieve high temperature superalloys. Some typical superalloy compositions are shown in figure 1. As can be seen in this figure, cobalt is a major alloying element in the nickel-base superalloys that are used for the disks, blades, vanes and combustors in aircraft gas turbine engines. Superalloys consume the major fraction (fig. 2) of U. S. cobalt imports - the U. S. imports more than 90 percent of its cobalt. In addition, the U. S. imports most of its highly refined chromium, tantalum, columbium, as

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well. All of these are key ingredients in high temperature superalloys. Often the sources of our imports are neither secure nor elastic to changes in demand (refs. 2 and 3).

Because of the "cobalt crisis" in 1978-1980 where cost sharply increased when the availability decreased, a flurry of strategic materials research activity was initiated by industry and government agencies. Faced with a potential cobalt shortage and high cobalt prices, industry (when possible) substituted established, "on-the-shelf" low/no cobalt containing materials for their high cobalt containing counterparts. This was accomplished particularly effectively in the magnet industry where ferrite magnets readily replaced samarium cobalt magnets. The aerospace industry was rapidly able to reduce cobalt consumption a modest amount by processing changes such as use of hot die forging to near-net-shape to replace conventional forging and by substitution of alternate, fully demonstrated low/no cobalt containing alloys (e.g., IN-718 for Waspaloy). In general, government responses included assessment of the options including stock-piling, expanded exploration, incentives to mining of lower grade ores, etc.

A longer range, more fundamental approach to this strategic materials problem was taken by NASA. Based on recommendations by the Gas Turbine Panel of ASTM/ASME/MPC (The American Society for Testing Materials/American Society for Mechanical Engineers/Metals Property Council), a NASA research program was initiated aimed, in part, at developing an improved understanding of the roles that cobalt, chromium, columbium, and tantalum play in the metallurgy, properties, and processing of nickel base superalloys (refs. 2 and 4 to 6). Longer term research efforts seek further reductions through advanced processing concepts and possible elimination of such elements through the identification of alternate materials. Early results from the initial phases of this program - called COSAM (Conservation of Strategic Aerospace Materials) - indicate that at least 50 percent and possibly all of the cobalt can be removed from many current nickel base superalloys used in gas turbine engines with little impact on mechanical properties and environmental resistance. More detailed property evaluation and fabrication efforts are underway or are still needed to confirm these findings.

Expected problems that could be faced in transferring such laboratory findings to actual hardware will be discussed in this paper. Case studies involving transfer of similar technologies - but perhaps more difficult than the alloying element substitution efforts - will be used to illustrate and discuss the rate-controlling steps involved. The roles that industry, universities, and government may have in such a transfer process will also be discussed.

BARRIERS TO TECHNOLOGY TRANSFER

In the case of new materials for use in gas turbine engines, the transfer of a researcher's idea through laboratory proof-of-concept to actual application can involve a time consuming, expensive process. Some of the barriers that retard this process are represented in figure 3 as a wall which must be climbed in order to reach the final application. In our model these "barriers" combine to determine the height of the wall in terms of the technical effort, cost, and time to reach the final application.

Well-defined need (component objective). - There must be clearly defined needs for a new material product or process as indicated in figure 3. In general, such needs have always been clearly articulated in the gas turbine

industry. Such engine needs include increased performance via higher operating temperature, increased durability, reduced fuel consumption, and cost reduction. Conservation of strategic materials recently loomed as a dominant need when cobalt, columbium, and tantalum prices skyrocketed as supplies dwindled. However, more recently, the economic downturn has now substantially reduced this crisis situation and returned it to the level of a long term chronic problem.

Funding. - Once a need is established, the overriding barrier is the availability of funding. If the potential payoff of a new material, process, or concept is judged to be significant, then time and money may be made available for technological investment. One distinguishing feature that often adds to the height of our wall in figure 3 is the frequent need to obtain funding from multiple sources. For example, in addition to the need for internal corporate support and funds, it is often necessary to establish cost sharing efforts between government and industry, or joint venture type arrangements between different industrial organizations. As a consequence, multiple source funding results in chronological fragmentation. For example, government agencies and/or industry may fund laboratory feasibility studies of a new material. Government agencies (such as NSF or NASA) may fund the early development and characterization efforts and the DOD may support the manufacturing technology costs. And frequently there are time gaps between such efforts due to various organizational budget schedules and procurement requirements. In fact, concentrated and commercialization-oriented funding by industry of a high risk technology may not occur until the component testing stage. Such complexities in the technology funding arrangements obviously can easily result in funding and effort disruptions and slippage, leading to increases in time and/or monetary costs for the development. In the limit, such disruptions can result in program termination, despite technical merit and promise. Some times such promising but terminated concepts are eventually picked up by a competing nation that is able to build on all the prior U.S. efforts.

Technology achievement. - For materials, other considerations in the "barrier wall" include technical achievement compared with competing materials. This barrier not only includes exceeding the current state-of-the-art, but also includes consideration of other new materials under development and thus represents a moving target. Usually even the same organization may sponsor, with equal priority, two or more alternatives to answer the same need. This is not unlike the approach practiced in the personal computers industry (ref. 7). In addition, the end-user periodically alters the initial objective as a consequence of preliminary results from competing developments or as a result of new market demands.

Timeliness. - Being able to move a development along on schedule is critical to being in a position to be fully ready to meet the specific needs of the engine application when the final selections are made.

Independent verification. - Confirmation of laboratory findings represents a formidable technology barrier. Often, process scale-up to large scale heats results in material properties that are below those achieved in the more ideally controlled laboratory scale processes. Additional effort must be expended to understand and remedy these deficiencies. Realization of the potential of a new material or process must be demonstrated on a practical basis - this usually means establishing one or two vendors qualified to make the material to specifications on a reproducible basis.

Manufacturability. - Material advances may necessitate modification of production fabrication equipment or even the purchase of new equipment. New

materials can require modified machining methods, alternate quality control techniques, etc.

Component reliability. - Manufactured prototype components must undergo extensive testing and evaluation to demonstrate the competitive edge of a new material or concept.

Designer and user acceptance. - New, unfamiliar materials can involve the need to make substantial component design changes as well as changes in the way a component is designed. Thus, there can be considerable iteration between design and component test before the designer develops enough confidence to incorporate the material in an engine. User acceptance can only occur when the system's reliability, performance and cost are firmly under control.

System reliability. - Overall system safety and reliability along with frequency of overhaul are barriers that must be addressed in the transfer process.

Entrepreneurship. - The barriers just described represent a complex system that must be overcome in the transfer of technology. An intangible coordination contribution from an entrepreneur in the materials development areas may well also be critical to the success or failure of the technology transfer. Gas turbine or jet engine manufacturers produce, or more to the point, design, assemble, and sell engines. They usually do not produce the initial alloys or process them. Depending on the article, the engine manufacturer may not even investment cast or machine to final shape. Consequently, besides the engine assembly component, there is an alloy production and refining component of the industry, a metal working and forming component, and a shape finishing component (ref. 8). As a rule, the various individual companies are independent of each other. Thus, an entrepreneurial person is also needed to shepherd establishment of a new technology in these various support organizations.

There is little doubt that all the problems associated with the cross-transfer of science and technology, including coordination of efforts, continuity of obtaining funds, and communications associated with diverse institutions exists in the gas turbine industry.

THE TECHNOLOGY TRANSFER PROCESS

The progress of a new alloy or a process concept to commercial maturity can be likened to climbing a ladder to surmount our technology transfer barrier wall (fig. 4). Each rung on this "technology transfer ladder" represents a science, technology, and/or development task that more or less has to be completed before ascending to the next one. The nature of each task, the number of tasks, and their order depend on the particular technology. For superalloys, in general, the beginning can be a concept for, say, introducing another class of strengthening particles in a new alloy (see following case studies), the development of thermal barrier coatings, or the replacement of cobalt in superalloys with a less import-sensitive element. The concepts or ideas need not be new, but these can be cross-transferred from another materials technology through knowledge gained from the literature or from personal contacts. The important point is that the "climbing" process can be less slippery if the innovation is in answer to well-defined needs and is following a structured plan to reach a production goal. The other tasks (fig. 4) basically correspond in content to those found in all other materials or process development where performance, reliability, and quality assurance are important, controlling parameters. The distinguishing differences for a gas turbine material are the high cost to qualify and certify a new material and the non-integrated

nature of the gas turbine industry wherein each different engine manufacturer has developed and/or demonstrated a number of its own component-specific materials.

To overcome the technology transfer barriers, a systematic program must be planned and successfully carried out (refs. 9 and 10). Steps involved to achieve success are suggested by the "technology transfer ladder" in figure 4. Generally, a researcher draws on a previously established technology base to build an idea or, in some instances, a new technology base must be established. Focused research to tailor the concept to a specific end-use need represents the second step in the development process. Normally, reiterations to optimize a material and/or process are required followed by extensive property characterization. At this point, a major decision must be made concerning scale-up from laboratory amounts of materials and small scale processes to production quantities of materials and manufacturing scale processes. Such scale-up can produce prototype hardware to complete evaluation. If a go-ahead is reached, a further major commitment of money is then required. Depending on the success of this phase of the program, eventual production of flight hardware and field testing will culminate the technology development efforts.

An example of the magnitude of such an undertaking is given by the single crystal turbine blade technology transfer effort. This effort has been estimated by Pratt & Whitney Aircraft to have taken 15 years and an investment of at least \$30 million dollars (ref. 11). This is about 5 to 7 years longer than the development of a conventional cast alloy and about 2 to 3 times more expensive.

The individual steps needed to carry a new alloy concept to ground engine testing will be traced to better illustrate some of the factors involved in the transfer of high technology materials. Alloy MA 6000¹ which is under development for advanced high temperature turbine blade application will be used as an example. The process for transfer of this alloy is currently in its final stages and should provide a good but perhaps conservative illustration of the problems impeding the progression of research alloys with low strategic metal content into flight hardware. The following can be viewed as a more difficult transfer problem since it is expected that the low strategic content alloys will cast, machine, and generally behave much like their predecessors.

CASE STUDY - MA 6000

Technical Achievements

The objective for what is now known as alloy MA 6000 was to develop a higher temperature, high strength nickel-base superalloy via the powder metallurgy route for turbine blade applications (refs. 12 to 15). Two key complicating factors were (1) processing by both mechanical alloying to achieve unique alloy compositions followed by gradient annealing to obtain a directionally recrystallized structure as compared with directionally solidified cast alloys, and (2) strengthening by both γ' precipitation and an oxide dispersion (ODS-oxide dispersion strengthening) versus gamma prime only strengthening in

¹MA 6000 - Trademark of International Nickel Co. (INCO).

cast alloys. The ultimate goal, if fully developed, was to allow higher operating temperatures while minimizing or eliminating cooling air penalties in aircraft gas turbine engines. Reduced use of cooling air can result in substantial reductions in specific fuel consumption (SFC). Figure 5 illustrates the relatively complex processing steps which are used to produce MA 6000. Special attention is drawn to the mechanically alloying concept using the high energy mill and development of a directional structure in the final processing step via use of a gradient annealing heat treatment.

Figure 6(a) is a very high magnification, transmission electron microscopy view (ref. 16) of the new MA 6000 superalloy. The black dots are inert oxide dispersoids that are stable to very high temperatures. The more or less squarish particles (fig. 6(b)), are the so-called coherent γ' and these have been used to strengthen superalloys at low and intermediate temperatures for 30 years. The innovation here is the marriage of both types of particles in the same system as well as the elimination of transverse grain boundaries through directional recrystallization (fig. 6(c)). The material property benefits are reflected in an alloy that behaves like high strength superalloys at low and intermediate temperatures, but its heat resistant strength does not fall off at the higher temperatures as do the strengths of the conventional superalloys.

Technology Base

It was not possible to quantitatively characterize the costs, time, and technical achievements that went into establishing the extensive technology base for MA 6000. The cornerstone for MA 6000's development was the invention of the mechanical alloying (MA) concept by Benjamin and its application to the development of simple nickel/chromium alloys such as MA 753, 754, and 755 (ref. 17). In addition to this technical achievement, the entrepreneurship of Benjamin and INCO (International Nickel Co.) plus that of Glasgow of NASA Lewis and Ewing of AVCO (now at DDA) must be viewed as intangible factors that led to the advance of this alloy from one showing laboratory promise to one nearing demonstration of commercial potential.

Technology Transfer History

Figure 7 shows the complicated extent of a number of sequential and overlapping projects involved in the development of MA 6000. (During development, the alloy was designated MA 6000E.) A key decision in the initial development process was made after evaluating the heat treating response of four preliminary experimental compositions. It was decided to sacrifice some possible high temperature solid solution strengthening by lowering the refractory metal content of the alloy so as to gain the advantage of a wide temperature "window" for the gradient annealing heat treatment.

Alloy characterization followed the initial alloy development and included determination of mechanical, environmental, and physical properties of MA 6000. Figure 8 is just a partial listing of the multitude and often expensive alloy characterization tasks for MA 6000 (ref. 13). Many laboratory tests are needed to simulate the complex stress-temperature environment missions required of jet engine materials. These tasks are typical of superalloy development programs and slow down the prompt transfer of a high potential laboratory alloy to commercial service since many long real time tests are necessary to provide a base for designer confidence.

University-based scientific research usually plays an inexpensive/cost-effective role in using science to help minimize the development times of high technology materials. Columbia University was involved in this capacity with respect to MA 6000. Questions on the relative roles of the different types of particles, of the matrix itself, and of unintentional inclusions were answered through systematic creep experiments (refs. 16, 18, and 19). The answers provided feedback for further mechanical alloy design. In similar studies, the concern over the view that oxide dispersion strengthened alloys have inherently low ductility was addressed. This issue was studied and it was concluded that low ductility is not a generic problem with mechanical alloys (ref. 18). It was also found that despite low ductility, notches do not weaken the high temperature static properties of MA 6000 and that under cyclic (dynamic) loading conditions, MA 6000 can indeed be superior to the more ductile conventional superalloys. Scale-up and characterization of the alloy, as also indicated in figure 7, expanded the scope of MA 6000 development program and involved the independent evaluation of a number of end-users within the engine manufacturing industry (ref. 14).

Current activities in the transfer process are twofold. A NASA funded contract is under way at TRW to direct forge MA 6000 into a turbine blade configuration (NAS3-22507). A second major NASA contract is under way at Garrett to carry MA 6000 blades into actual engine testing (NAS3-20073). The latter effort is part of NASA's MATE Program which has as its objective the accelerated determination of readiness of promising but higher risk technologies for commercial gas turbine engines. The objectives of the Garrett program are shown in figure 9(a), and the current schedule for completion is listed in figure 9(b). The primary objective is to determine the potential of MA 6000 via engine test of prototype blades such as shown in figure 10. The successful completion of this phase of the transfer process would constitute a major milestone toward the commercialization of MA 6000 for engine hardware. Another important point is that based on such government and university involvement, recent increases in INCO's internal funding levels for MA 6000 have been made available and MA 6000 is now being developed at INCO by means of an internal venture group (INCOMAP), which oversees development and production, but is independent of existing operating profit centers. This venture type organizational scheme allows more monies to be reinvested into further developments than is ordinarily practiced by normal profit centers.

MA 6000 Transfer Barriers

Given a brief history of the technical development of MA 6000, we will now examine some of the barriers highlighted in figure 3. Focused research on optimization of the composition of MA 6000 began in 1974. Current plans call for the MA 6000 MATE Blade Project to continue through mid-1984, a period of about 11 years. If engine testing is successful in this program, it is estimated that at least 5 more years will be required to fully scale-up this material and gain flight hardware experience before the alloy can be considered to have transferred from a laboratory concept to full commercial turbine blade application. This represents a time barrier of about 16 years for the transfer of MA 6000. This is about the same time as that taken to transfer single crystal airfoil technology - both involved new process technology in addition to a new alloy concept and composition.

The estimated investment profile for development of a γ' /ODS blade alloy by INCO is shown in figure 11. This profile starts with initial development

and extends through focused research supported jointly by INCO and NASA, to blades undergoing ground engine tests. In figure 11 the estimated accumulated costs for the transfer of MA 6000 are shown. At the current level of investment by INCO in the INCOMAP Project and by NASA in the MATE Blade Project (which extends to 1984), a total cost of at least \$5 million will have been expended by NASA and INCO alone. And additional support by other organizations that were investigating the potential of this material was made during this period. In the future additional expenditures for distributed production scale-up, manufacturing, etc., are still required.

The third major barrier to overcome for successful transfer is the extent of the advance in technical accomplishment that must be achieved by a new alloy or process. Figure 12 shows the progress in stress-rupture capability of superalloys over the past 40 years (ref. 20). Alloy MA 6000 offers a substantial advance in use temperature over those of other alloy developments to date. Alloy DS MAR-M247 (member of the DS MAR-M200 alloy family), a directionally solidified advanced blade alloy is used as the reference material for the MATE Blade Project. MA 6000 exceeds the creep and fatigue properties of this alloy based on laboratory tests. The goal of the MATE Blade Project is to increase the temperature capability of turbine blades by 150° to 200°F compared with MAR-M247. The key to achieving this goal is to maintain the advantage shown in figure 11 in scaled-up heats and in fabricated components.

We have discussed the transfer history of MA 6000 and the major barriers to this process which include time, cost, and technical achievement. Designer acceptability still must be achieved along with overcoming other barriers suggested in figure 3. It is estimated that about 5 years of full-scale development will be required past the MATE Blade Project before MA 6000 can reach production blades (and possible vanes) in gas turbine engines. Figure 13 shows the actual innovation ladder for MA 6000. We had some problems in deciding where the bottom of the ladder should be. Should it start at about 1965, which was when Benjamin first started on the long journey to produce the MA 6000 type alloy, or should it be 1974, which was when NASA started to fund Benjamin and co-workers at INCO to design the final alloy composition that later became MA 6000? Even taking this latter date, it appears that about 16 years will have elapsed and between \$10 and \$12 million dollars will be expended before the MA 6000 alloy can be expected to pass through engine testing and qualify for mass production.

The step of full-scale development (fig. 13) lies ahead for MA 6000. The next section will briefly consider only this step for a second case study.

CASE STUDY - TBC FOR VANE PLATFORMS

Thermal barrier coatings (TBC), as their name implies, are used to reduce the metal operating temperatures of air-cooled high temperature metallic components of gas turbine engines by insulating them from the hot combustion gases. This ceramic-coating insulation reduces the metal temperatures by 200° to 300°F less than would be experienced for a conventional air-cooled component (fig. 14(a)). Lower metal temperature offers neither extended component life with constant levels of cooling air or allows reductions in cooling air and increased efficiency at constant life. In addition, the TBC's oxidation/corrosion resistance is generally superior to that of the metal substrate, thus providing added environmental protection.

Thermal barrier coatings have gained acceptance in several applications on static engine components and hold promise for future applications on rotating turbine blades, as illustrated in fig. 14(b). Initial efforts aimed at

insulating coatings for both aircraft and rocket engines (i.e., the X-15, etc.) eventually led to the use of an early generation of thermal barrier coatings in gas turbine combustor liners. The barriers to incorporation were minimal here since the coating was merely applied on a static structure to extend life - it was not "designed" into the combustor performance/structure.

The use of TBC's on vane platforms (end walls) for the JT9D engine (unpublished report by K. D. Shebbler and R. A. Graziani of Pratt & Whitney Aircraft Group) will be briefly discussed as an example of a full-scale development step in the transfer process. Despite previous experiences, there were still barriers to this phase of technology transfer. These barriers took the form of designer acceptance since the coating would be used to replace costly platform cooling - expensive hole drilling - plus would improve performance due to reduced cooling air injection requirements. The coatings would thus require component retro-fit in existing engines being used in the commercial fleet. Another barrier would be airline acceptability which would depend on retro-fit cost, pay-back time, and on any problems that might arise in commercial service. Major tasks undertaken in this project included coating deposition process refinement, design, and concept coordination. The performance improvement sought (and gained) was a reduction in platform cooling air by 44 percent which would lead to more efficient engine operation and estimated fuel savings of 0.2 percent. This project demonstrated the feasibility of applying the technology of plasma sprayed TBCs to turbine vane platforms in modern high temperature commercial engines. The time and estimated cost barriers for this single step in the technology transfer process are shown in figure 15. Despite the technology base, even this relatively straightforward project took about 3-3/4 years and an investment of nearly \$2 million dollars. This development concept is currently being slated for future builds of advanced gas turbine engines.

CASE STUDY - AEROSPACE STRATEGIC MATERIALS

Strategic materials such as Cr, Co, Ta, and Cb are critical to the manufacture of modern gas turbine engines, as indicated in figure 16. NASA's COSAM Program has as one of its major objectives the development of the needed understanding of the roles of strategic elements in nickel-base superalloys so as to guide either the lowering of strategic element content or their total elimination by replacement with nonstrategic elements. Such scientific achievements would help reduce use of strategic elements and so lower the U. S. dependence on foreign imports which now range from 90 to 100 percent for Cr, Co, Ta, and Cb. Results of the initial phase of the COSAM Program, which involved substituting nickel for cobalt in several superalloys, suggest that up to 50 percent and possibly all of the cobalt can be removed from some of these alloys without degrading mechanical properties, as illustrated in figure 17. In addition, this reduction in cobalt may result in an improvement in environmental resistance, as shown in figure 18 (ref. 6). It should be pointed out that, in attempting to minimize the problems with acceptance and other technology transfer problems, the NASA cobalt project by initial design involved from the onset the NASA Lewis Research Center (government laboratory), several universities, and a superalloy producer.

Figure 19 suggests the follow-on augmentation that may be required to transfer the COSAM research results to actual flight hardware. In the case of modifying the composition of a currently used nickel-base superalloy to reduce

the strategic element content, it is anticipated that the technology transfer will not take as long nor be as costly as developing a new material such as MA 6000. For example, the development of MA 6000 involved a major activity aimed at the processing and manufacture of this alloy. However, with the recent reduced consumption of cobalt worldwide along with improved supply and a drop in price the impetus for substituting for cobalt has been removed. Therefore, this technology transfer may be delayed until the need arises. Indications are that reducing cobalt will not require extensive development to manufacture components from reduced cobalt alloys, but will only require slight modifications in casting or working temperatures and heat treating conditions. Although these steps represent only a small portion of the overall cost of technology transfer, they will help to hold down the overall cost. It is estimated that the transfer process will proceed as indicated in figure 20 (from "Technological Alternatives"). Time to provide flight hardware may range from 6 to 7 years at an investment of \$6 to 9 million dollars depending on which components (blades, vanes, disks, etc.) are selected for an augmentation project. Since these estimates reflect current/future dollar values, the total real costs are expected to be considerably less than those of single crystals and MA 6000. The times reflect long real-time testing requirements and normal new alloy production scale-up efforts.

In the case of strategic materials, an additional major barrier to transfer of laboratory technology is the cyclic behavior of prices and availability of specific strategic materials. When demand and prices are high and supplies become limited or cut-off, there is a great interest in substituting low/no strategic metal containing alloys for those in current use with high strategic metal content. However, when strategic metal prices drop and material is readily available, then the normal major barriers of cost, technical achievement, and timeliness are of prime importance and conserving strategic materials is of minimal concern. Hence, the internal corporate needs are low and are reflected in low need for government or university involvement. Funds are then diverted and efforts are substantially reduced or cancelled - until the next crisis in material cost and supply develops.

CONCLUDING REMARKS

The COSAM Program as now constituted focuses in part on basic understanding of the roles of strategic elements in nickel base superalloys so as to allow reductions through substitution. The transfer of low/no strategic content superalloy technology faces two extreme scenarios. One is that strategic materials shortages are cyclic and of short duration in nature and that a free market system, operated by private enterprise with minimal Federal Government intervention, has and will continue to meet U. S. industrial needs. The other perceives the possibility of a total cut-off of strategic materials and the need for a federally-supported materials "technology bank" ready for technology withdrawals in the event of such a cut-off for an extended duration. This paper has discussed the barriers that exist for the transfer of laboratory-base R&T concepts to a point of incorporation in hardware production. Technology achievement/payoff, cost, and time are the primary barriers that must be considered before embarking on such a technology transfer process. Substitution of critical alloying elements is projected to require less cost and time than some of the examples provided here or that could be considered for new alternative materials, also be investigated in the COSAM Program.

The case studies selected for discussion were mainly made on the basis of information available to the authors. Other ongoing developments in superalloys may no doubt serve equally well as case studies to underscore the barriers that exist in the science-to-technology-to-commercialization transfer process of hot section turbine materials. In fact, we perceive a need for the gas turbine materials community to study these issues further to determine how the total cost and total time for transferring low/no strategic alloys to engine readiness can be minimized. There is a need to develop plans and formulate rational funding and coordination schemes that will substantially lower transfer barriers so as to allow rapid, low cost application of this technology should acute or chronic supply or price instabilities arise.

The many strategic uses of the high temperature superalloys demand the long-term planning, research, and development actions that may not be consistent with the current economic policies of the industrial profit centers. Accordingly, it is imperative to maintain government/university/industry partnerships to continue to develop the understanding necessary to minimize future U. S. vulnerability in the area of strategic materials.

REFERENCES

1. J. Newhouse: The Sporty Game, Alfred A. Knopf Publisher, New York, 1982.
2. J. R. Stephens: Mater., Eng., 1981, vol. 94, pp. 26-29.
3. J. K. Tien, T. E. Howson, G. L. Chen, and X. S. Xie: J. Metals, vol. 32, 1980, pp. 12-20.
4. J. R. Stephens: NASA TM-81617, National Aeronautics and Space Administration, Washington, D.C., 1980.
5. J. R. Stephens, NASA TM-82852, National Aeronautics and Space Administration, Washington, D.C., May 1982.
6. J. R. Stephens, NASA TM-83006, National Aeronautics and Space Administration, Washington, D.C., October 1982.
7. T. Kidder, The Soul of a New Machine, Avon Press, New York, 1982.
8. W. J. Boesch, J. K. Tien, and T. E. Howson, Met. Prog., 1982, vol. 122, no. 5, pp. 49-56.
9. D. Fishlock, The New Scientists, Oxford University Press, England, 1971.
10. D. J. deSolla Price, Little Science, Big Science, Columbia University Press, New York, 1963.
11. Mach. Des., 1982, vol. 54, no. 5, p. 52.
12. H. F. Merrick, L. R. Curwick, and Y. G. Kim, NASA CR-135150, National Aeronautics and Space Administration, Washington, D.C., January 1977.
13. Y. G. Kim and H. F. Merrick, NASA CR-159493, National Aeronautics and Space Administration, Washington, D.C., May 1979.
14. R. C. Benn, NASA CR-165124, National Aeronautics and Space Administration, Washington, D.C., July 1980.
15. T. K. Glasgow, NASA TM 79088, National Aeronautics and Space Administration, Washington, D.C., April 1979.
16. T. E. Howson, D. A. Mervyn, and J. K. Tien, Metall. Trans. A, 1980, vol. 11A, no. 9, pp. 1609-1616.
17. J. S. Benjamin, Metall. Trans., 1970, vol. 1, no. 10, pp. 2943-2951.
18. O. Ajaja, T. E. Howson, S. Purushothaman, and J. K. Tien, Mater. Sci. Eng., 1980, vol. 44, pp. 165-172.
19. M. E. McAlarney, R. M. Arons, T. E. Howson, J. K. Tien, and S. Baranow, Metall. Trans. A, 1982, vol. 13A, no. 8, pp. 1453-1462.
20. R. F. Decker, in Superalloys 1980, pp. 1-20, American Society for Metals, Metals Park, Ohio, 1980.

ALLOY	NOMINAL COMPOSITION										TYPICAL USE
	Ni	Cr	Co	Mo	W	Ta	Re	Al	Ti	Hf	
WASPALLOY	58	20	13	4	--	--	--	1.3	3	--	TURBINE DISKS
UDIMET-700	53	15	19	5	--	--	--	4.3	3.5	--	TURBINE DISKS
MAR-M 247	60	8	10	.6	10	3	--	5.5	1	1.4	TURBINE VANES
RENE' 150	59	5	12	1	5	6	3	5.5	--	1.5	TURBINE BLADES
HA-188	22	22	39	--	14	--	--	--	--	--	COMBUSTORS

Figure 1. - Compositions and typical uses of some common aerospace superalloys.

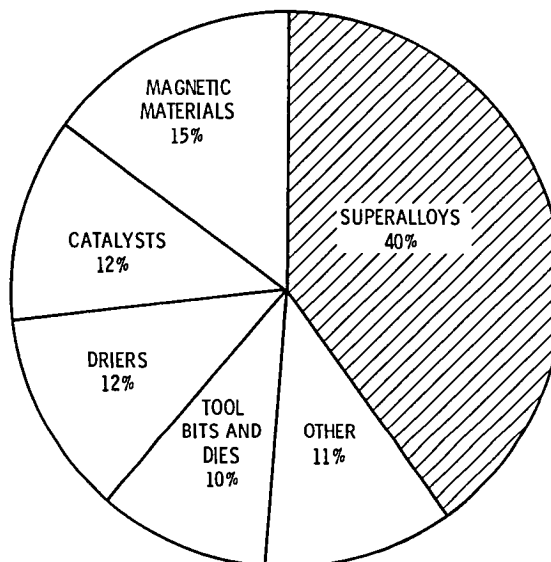


Figure 2. - Distribution of 1981 U. S. cobalt consumption - 13.6 million pounds.

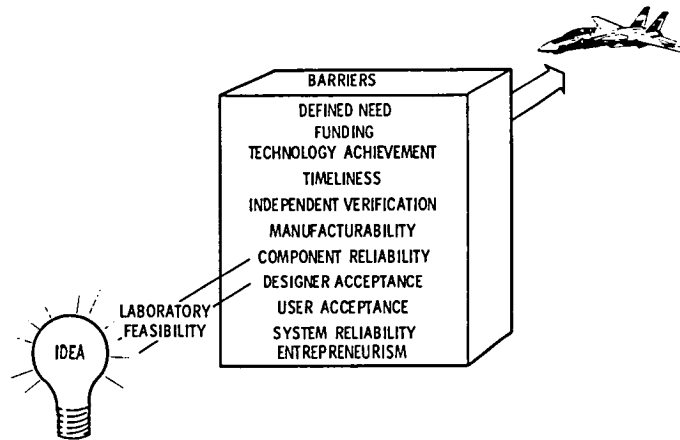


Figure 3. - Technology transfer barriers.

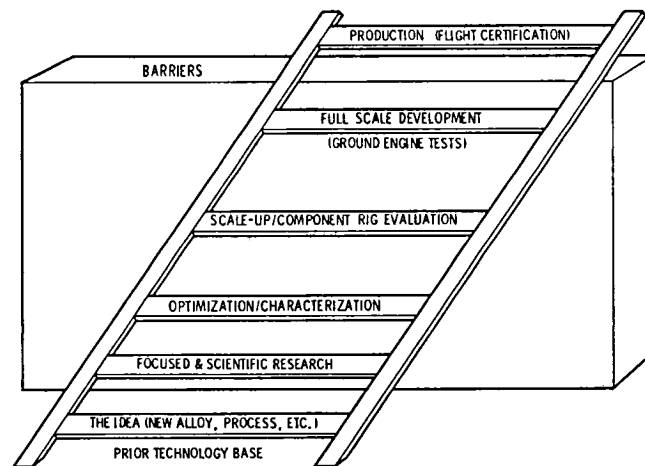


Figure 4. - Technology transfer ladder.

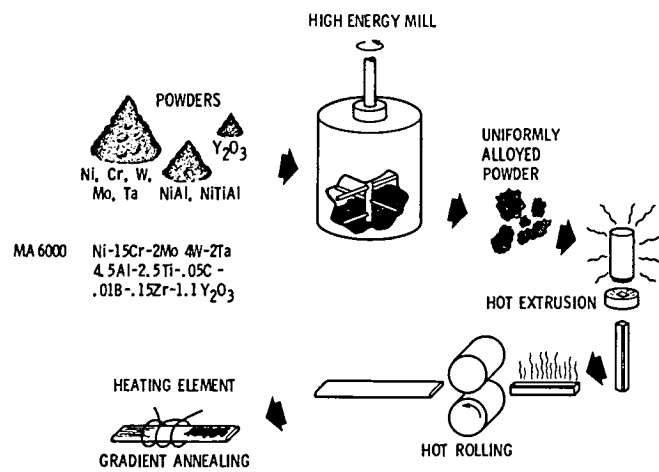
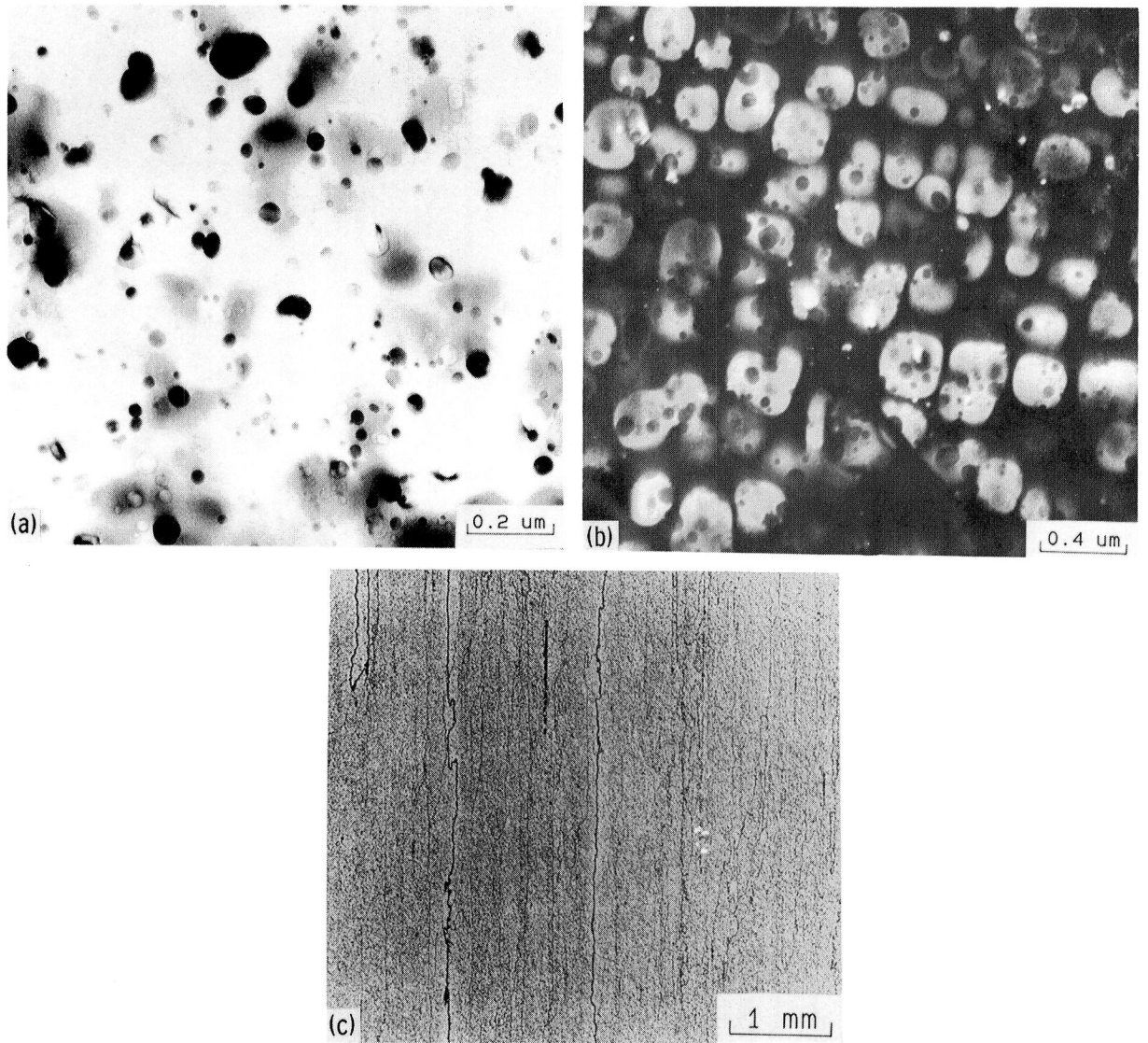


Figure 5. - Process for manufacture of an oxide dispersion strengthened superalloy.



(a) oxide dispersoids

(b) gamma prime precipitates

(c) elongated grain structure

Figure 6. - Microstructures of MA6000 showing strengthening phases and elongated grain structure.

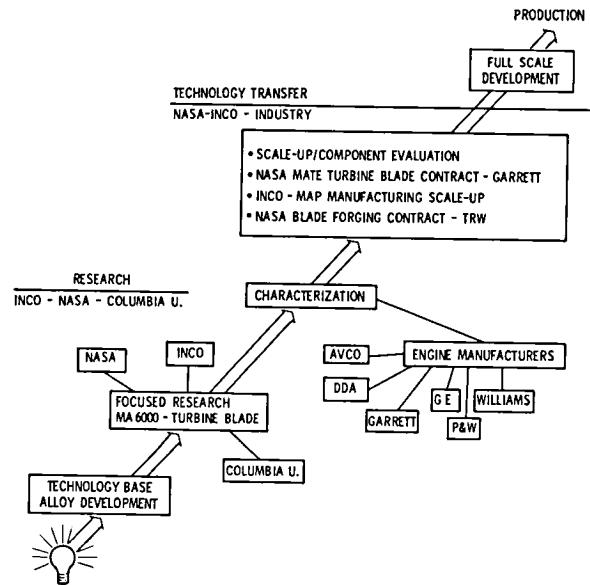


Figure 7. - Technology transfer history for MA 6000.

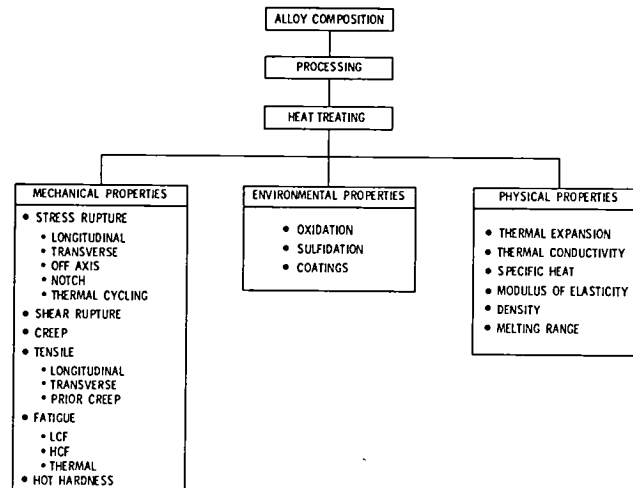


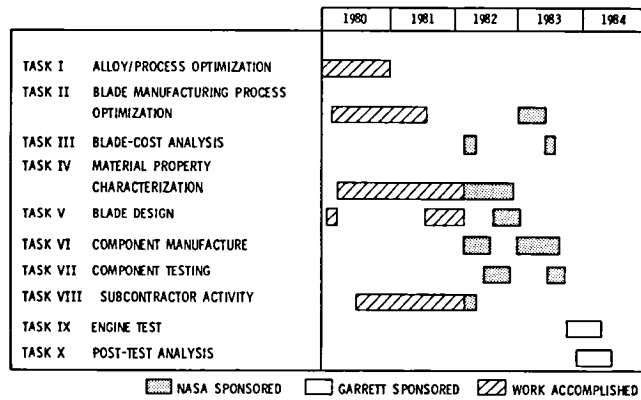
Figure 8. - Alloy characterization for alloy MA 6000.

OBJECTIVES

- SCALE-UP AND OPTIMIZE PROCESSING OF OXIDE DISPERSION STRENGTHENED (ODS) MA6000 ALLOY
- DEVELOP BLADE MANUFACTURING TECHNIQUES
- EVALUATE MATERIAL PROPERTIES
- DESIGN UNCOOLED LOW-STRESS TURBINE BLADE
- EVALUATE TURBINE BLADE THROUGH COMPONENT TESTING
- DEMONSTRATE MA6000 TURBINE BLADE THROUGH ENGINE TESTING

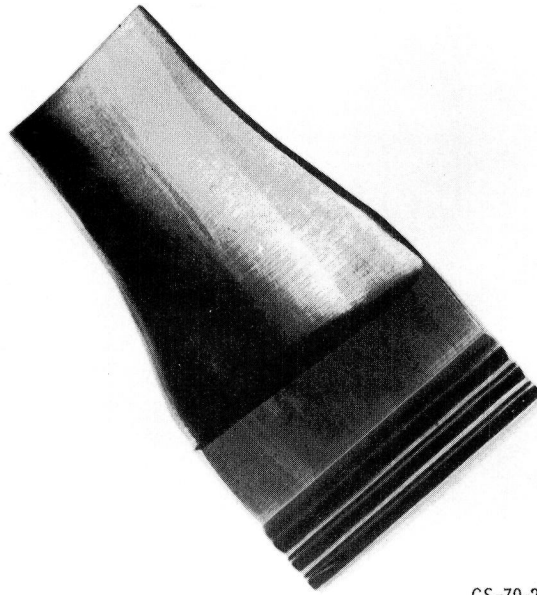
(a) Objectives.

Figure 9. - ODS turbine blade project.



(b) Schedule.

Figure 9. - Concluded.



CS-79-2413

Figure 10. - Prototype MA6000 turbine blade.

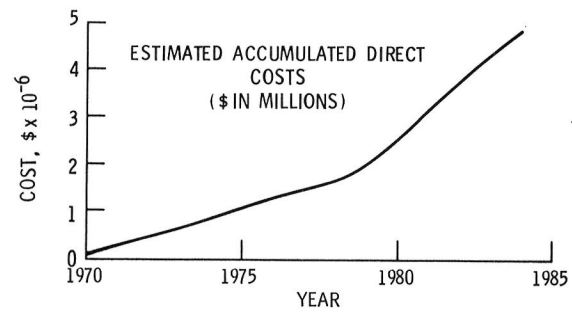


Figure 11. - Cost transfer for MA 6000.

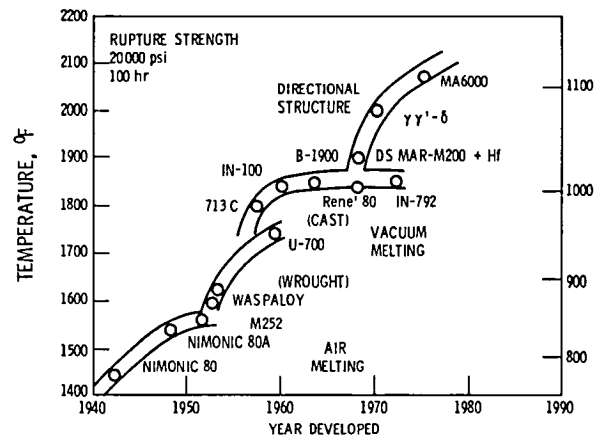


Figure 12. - Progress in turbine blade materials.

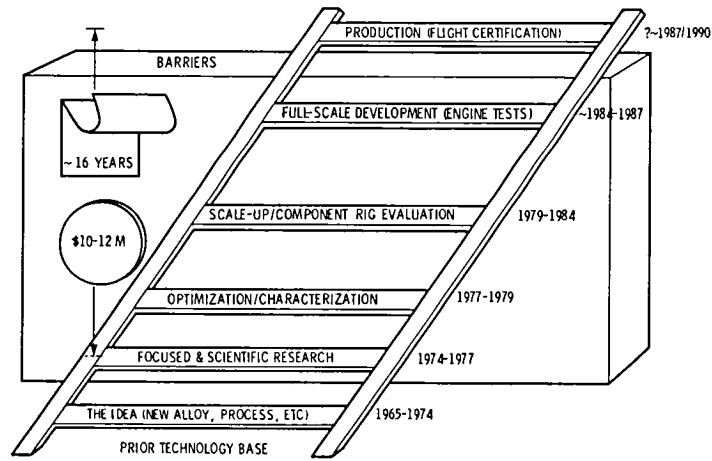
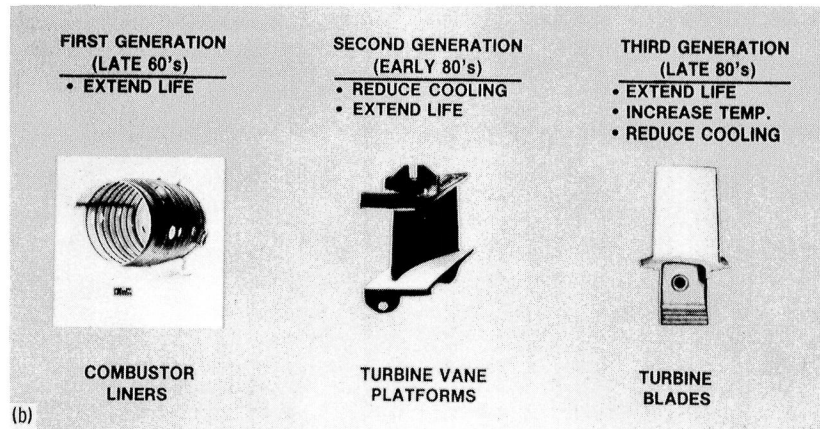
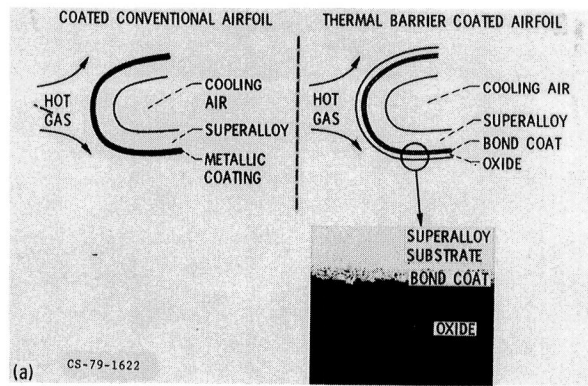


Figure 13. - Technology transfer ladder for the dispersion strengthened alloy MA 6000.



(a) TBC concept

(b) TBC applications

Figure 14. - Thermal barrier coatings (TBCs) for gas turbine engines.

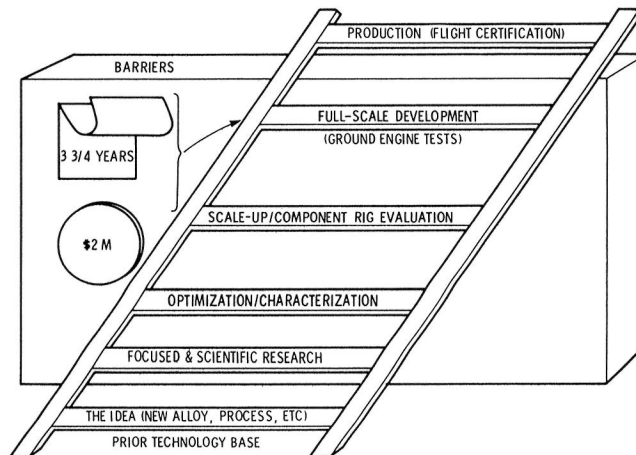


Figure 15. - Technology transfer ladder for thermal barrier coatings on turbine vane platforms.

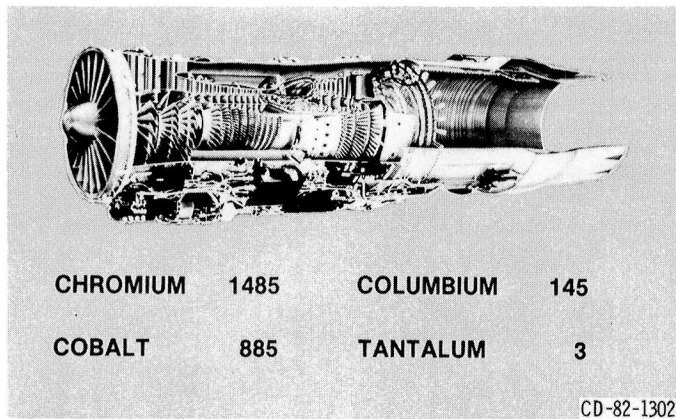


Figure 16. - F100 engine strategic materials requirements in pounds.

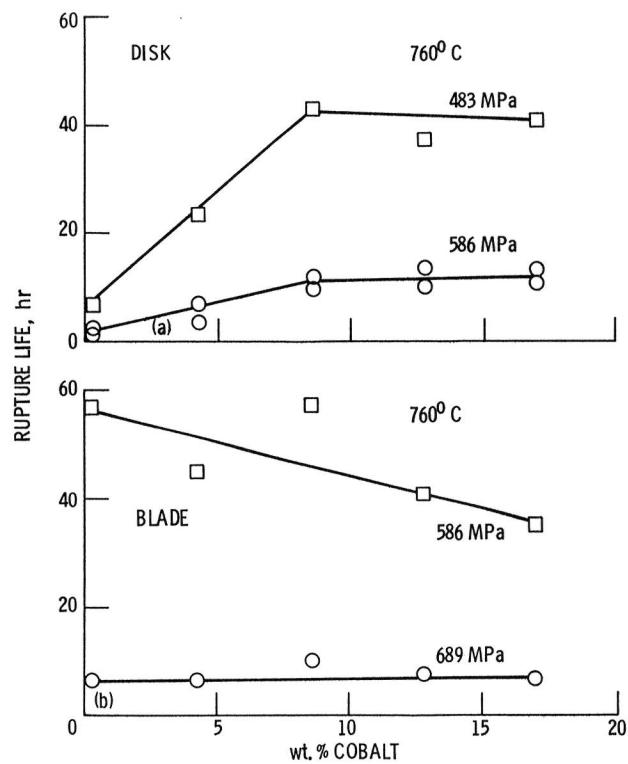


Figure 17. - Stress rupture lives of Udiment 700 as a function of cobalt content for (a) the disk heat treatment and (b) the blade heat treatment.

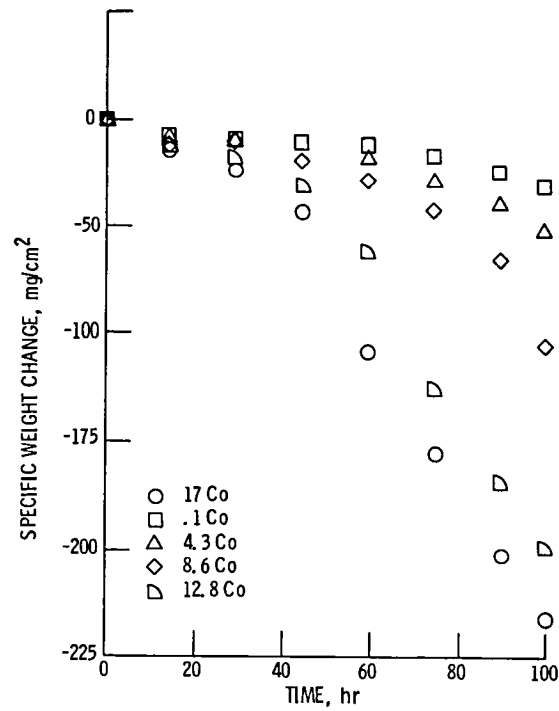


Figure 18. - Cyclic oxidation weight change results for reduced cobalt Udimet 700 alloys.

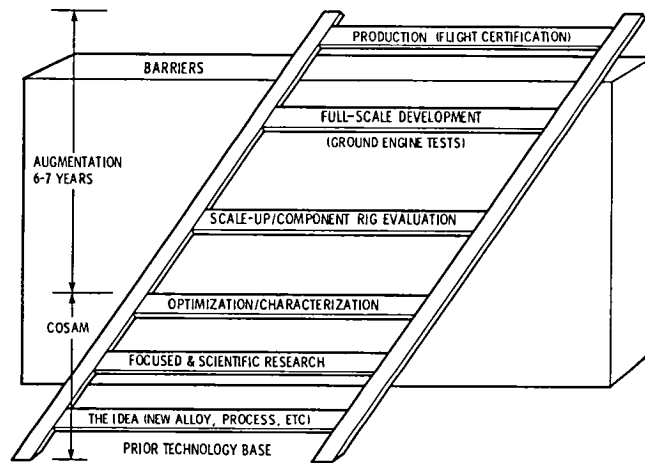


Figure 19. - Technology transfer ladder for strategic material substitution.

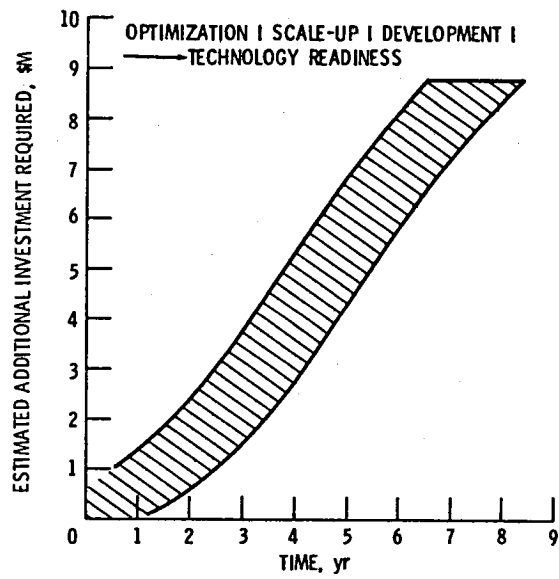


Figure 20. - Estimated cost/time to transfer a strategic material substitution technology.

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16. Abstract A typical innovation-to-commercialization process for the development of a new hot section gas turbine material requires one to two decades with attendant costs in the tens of millions of dollars. This transfer process is examined to determine the potential rate-controlling steps for introduction of future low strategic metal content alloys or processes. Case studies are used to highlight the barriers to commercialization as well as to identify the means by which these barriers can be surmounted. The opportunities for continuing joint government-university-industry partnerships in planning and conducting strategic materials R&D programs are also discussed.					
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